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ERDEC-CR-227

**ADSORBENT EVALUATION AND ADSORPTION EQUILIBRIUM DATA
FOR R-123, R-134a, AND TOLUENE
ON SELECTED ACTIVATED CARBONS, SILICA GELS, AND
POLYMERIC RESINS**

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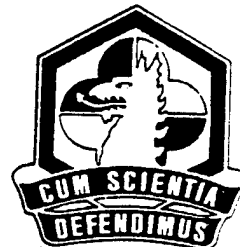
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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave Blank)		2. REPORT DATE 1997 July		3. REPORT TYPE AND DATES COVERED Final; 94 Sep - 96 Jan
4. TITLE AND SUBTITLE Adsorbent Evaluation and Adsorption Equilibrium Data for R-123, R-134a, and Toluene on Selected Activated Carbons, Silica Gels, and Polymeric Resins			5. FUNDING NUMBERS C-DAAA15-93-C-0070	
6. AUTHOR(S) Croft, David T., and Maurer, Scott M.				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Guild Associates, Inc., 5022 Campbell Boulevard, Baltimore, MD 21236			8. PERFORMING ORGANIZATION REPORT NUMBER ERDEC-CR-227	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) DIR, ERDEC, ATTN: SCBRD-RT/ASM, APG, MD 21010-5423			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES COR: David Reed, SCBRD-RT/ASM, (410) 671-8212				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) Adsorption equilibria data have been measured for refrigerant R-123 vapor on Rohm and Haas Ambersorb 563; Calgon Carbon BPL activated carbon and CAL liquid phase carbon; Kansai Coke and Chemical Company Maxsorb G505Z30; Norit RD2030; Adcoa silica gel, 408 and 59; and Dow polymeric resin XUS 40285.00 and XUS 43493.01 at several temperatures over a wide range of partial pressures. Isotherms were measured for R-134a on BPL activated carbon, Sorb-Tech coconut shell carbon, and silica gel 59. Toluene isotherms were measured on BPL, coconut shell carbon and silica gel 59. The data were correlated using the Dubinin-Astakhov equation. Adsorption properties are summarized by the partition function, which is a measure of capacity, and the dimensionless derivative, which is a measure of favorability.				
14. SUBJECT TERMS Partition function Favorability DAE			15. NUMBER OF PAGES 26	
Dubinin-Astakhov Equation Adsorption equilibria Dimensionless derivative			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED		18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL

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PREFACE

The work described in this report was authorized under Contract No. DAAA15-93-C-0070. This work was started September 1994 and completed January 1996.

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ADSORBENT EVALUATION AND ADSORPTION EQUILIBRIUM DATA FOR R-123, R-134a, AND TOLUENE ON SELECTED ACTIVATED CARBONS, SILICA GELS, AND POLYMERIC RESINS

1. INTRODUCTION

Choosing the best adsorbent(s) to use in a given application requires consideration of both adsorption capacity and the shape (favorability) of feed component adsorption isotherms. Adsorption will be characterized in this report by: (1) capacity (the ratio of the amount of adsorbate in the adsorbed phase to the amount in the vapor phase), and (2) adsorption "favorability" (related to the concavity of the isotherm). A higher capacity allows a smaller unit to perform the same separation. High capacity appears to be desirable; however, high capacity is often only possible (especially at low feed concentrations) when the adsorption isotherm is highly favorable. For single-use applications, both high capacity and strong favorability are desired. When the adsorption isotherm is highly favorable, the adsorbent becomes difficult to regenerate in a cyclic process. Therefore, either useful capacity is reduced or increased purge is required. Choosing the best adsorbent(s) for a given application may not be a simple task and may involve solving a difficult optimization problem.

The following investigation reports on adsorption isotherms measured for three adsorbate chemicals on several adsorbents. The Dubinin-Astakhov equation is used to fit selected data. A means of characterizing and comparing adsorption isotherms is proposed that takes into account the adsorptive capacity and the adsorptive favorability of the challenge chemical/adsorbent pairs considered. The experimental data are presented in the Appendix in a series of tables. Development of a rigorous systematic means of determining the best adsorbent for a particular process application is left for later work. This may be done by application of the "Direct Determination" methods to optimization described in Croft.¹

2. EXPERIMENTATION

2.1 Apparatus.

Except for changes to the sample temperature measurement and control system, the apparatus used was the same as that used by Mahle, et al.,² and is described in that reference. The apparatus described by Mahle, et al., controlled the temperature of the adsorbent by immersion of the sample container in a water bath. The sample container used for measuring the data reported here was surrounded by a water jacket. A water/ethanol mixture from the water bath was circulated through the jacket to regulate temperature over the range from 0 °C to 50 °C. Resistance heating coils in the jacket supplied heat and regulated temperatures for set-points 50 °C and above. This arrangement provided three advantages: (1) the sample container remained dry so drying the sample container before changing adsorbent was not required, (2) the resistive

heaters could bring the sample to higher temperatures, and (3) when the water jacket was drained, high temperature experiments could be conducted without the safety hazard posed by circulating hot liquids. For experiments conducted prior to October 11, 1995, a glass jacket with a vertical orientation was used. After that date, the glass jacket was replaced by a larger copper jacket with a horizontal orientation. A detailed description of changes to the sample temperature control and measurement system of the apparatus may be found elsewhere.³

2.2 Materials.

The adsorbate chemicals used in this study were DuPont 2,2-dichloro-1,1,1-trifluoroethane (R-123), Aldrich 99+% 1,1,1,2-tetrafluoroethane (R-134a), and Sigma-Aldrich 99.8% toluene (Lot # 07117MG). The adsorbents used in the experiments were Amborsorb 563 (Rohm & Haas), BPL activated carbon (Calgon Carbon Co., Lot 7816-V) and CAL liquid phase carbon (Calgon Carbon Co.), coconut shell char carbon (Sorb-Tech Inc., Type CL-13, 8/16 Mesh), Maxsorb G505Z30 (Kansai Coke and Chemical Co.), RD2030 (Norit), silica gel grade 408 (Adcoa, 12/28 Mesh), silica gel grade 59 (Adcoa, 4/8 Mesh), polymeric resin XUS 40285.00 (Dow Chemical Co., 20/28 Mesh), and polymeric resin XUS 43493.01 (Dow Chemical Co., 20/28 Mesh).

2.3 Procedure.

The general procedure involved: (1) determining the dry weight of the adsorbent sample, (2) pressure testing the apparatus, and (3) starting the automated adsorption isotherm system. Most samples were prepared by placing approximately 250 mg of adsorbent in a Mettler LJ16 Moisture Analyzer. The moisture analyzer was set to heat to 150°C and the minimum weight measured with the drying balance was assumed to be the dry weight of the adsorbent sample. Heating times were typically about 5 minutes. The sample was then placed into the isotherm apparatus and purged with flowing nitrogen. Following this, the isotherm apparatus was pressure tested at approximately 25 psia for 20 minutes. The system was then slowly depressurized to atmospheric pressure and the isotherm measurement program was initiated.

3. RESULTS AND DISCUSSION

The R-123, R-134a and toluene experiments performed are summarized in Table 1. Table rows are labeled with the adsorbent type and the columns are labeled with the adsorbate chemical. The set point temperatures at which data were measured are listed in the table. The measured isotherm data are presented in Tables A1 through A25 in the Appendix. The data tables are labeled with the date the automated apparatus was started. Generally, three isotherms were measured in each experiment. When the isotherm temperature set points were 50 °C or below, the jacket, and thus the adsorbent sample, was regulated by circulating a water/ethanol

mixture from the water bath. When the set point temperatures were 50 °C or higher, the liquid was drained from the jacket and the resistive heaters were used to control the temperature.

Table 1. Adsorption Isotherms for 3 Organic Vapors (Temperatures are Set Point Temperatures)

	R-123	R-134a	TOLUENE
AMBSORB	10, 25, 500 °C		
BPL	10, 25, 50, 100, 150 °C	10, 25, 50, 100, 150 °C	25, 50, 100, 150 °C
CAL	0, 25, 50 °C		
COCONUT		10, 25, 50, 100, 150 °C	0, 25, 50, 100, 125, 150, 200 °C
MAXSORB	0, 25, 50 °C		
NORIT	0, 25, 50 °C		
SIL. GEL 59	0, 25, 50 °C	10, 25, 50 °C	0, 5, 10, 15, 20, 25, 50 °C
SIL. GEL 408	0, 25, 50 °C		
XUS 43493.01	10, 25, 50 °C		
XUS 40285.00	0, 25, 50 °C		

The jacket surrounding the adsorbent sample container made of glass was used for experiments conducted before October 11, 1995. Experiments conducted after this date used the copper jacket adsorption bed configuration. The change was made when it was determined that the glass jacket did not evenly distribute heat across the length of the sample container when the resistive heater was used. The higher thermal conductivity of the copper allowed for more uniform temperature distribution and, thus, better temperature control. With the glass jacket a 14 °C temperature gradient was measured across the sample container when the set point was 175 °C. With the copper jacket, the measured temperature gradient at a 150 °C set point was only 1 °C³. The better temperature control with the copper jacket was essential for the high temperature data measured for toluene where set point temperatures of 200 °C were used. The accuracy of the data measured with the copper jacket is expected to be better than the data measured using the glass jacket as temperature set points are increased.

Selected data was correlated using the Dubinin-Astakhov (D-A) equation. The D-A equation may be written in the form (Mahle, et al.²)

$$\ln p = \ln p_{sat} - \frac{\beta E}{RT} (-\ln \theta)^{1/m} \quad (1)$$

where p is the partial pressure over the adsorbent, p_{sat} is the liquid saturation partial pressure, βE a constant characteristic energy of interaction, R is the gas constant and T the absolute temperature. Here, the fractional loading is defined $\theta = q/q_{sat}$ where q is the adsorbed-phase concentration and q_{sat} is the adsorbed-phase concentration at equilibrium with the liquid saturation pressure. An Antoine equation was used to calculate the saturation vapor pressure of R-123. The coefficients giving the partial pressure in Pascals are $A = 21.20$, $B = 2588$ and $C = -33.5$. Fit parameter results are shown in Table 2. These values were calculated using a least squares best fit. The data was fit by minimizing the variance defined $\sigma^2 = \sum_i (\ln p_e - \ln p_m)^2$ where

the subscripts *e* and *m* denote experiment and model, respectively. Values of the minimum variance are also listed in the tables.

Table 2. R-123 Dubinin-Astakhov Fit

ADSORBENT	AMBERSORB	BPL	CAL	MAXSORB	NORIT
$q_{sat} (mol/kg)$	1.62	4.28	3.21	9.02	1.86
$\beta E/R (1/K)$	2910	2150	2390	1460	3020
<i>m</i>	2.31	1.86	2.04	1.61	2.96
σ^2	1.94	1.82	1.332	0.721	1.80

ADSORBENT	SIL. GEL 59	SIL. GEL 408	XUS 43493.01	XUS 40285.00
$q_{sat}(mol/kg)$	1.60	2.34	3.14	5.01
$\beta E/R (1/K)$	866	1370	1950	1720
<i>m</i>	1.63	1.89	2.41	1.88
σ^2	1.51	0.454	0.386	1.18

The capacity of the adsorbent is characterized by the partition function for an adsorption bed and is defined as

$$\Lambda = \frac{\rho_b q_{ref}}{\epsilon c_{ref}} \quad (2)$$

where ρ_b is the bulk density of the adsorbent packing, q_{ref} is the loading in moles chemical per mass adsorbent in equilibrium with the feed concentration, ϵ is the packing void fraction, and c_{ref} is the feed concentration. For a single-pass filter, Λ may be used to calculate the breakthrough time for the stoichiometric center of the adsorption wave.

The “favorability” of the adsorption isotherm may also be of concern. An isotherm which is concave downward has an increasing partition coefficient as vapor-phase partial pressure decreases. This results in high adsorbed-phase concentrations even at low vapor-phase concentrations (called “favorable adsorption”). Although desirable in single-pass applications, favorable adsorption can become a problem for cyclic systems (e.g., PSA) where desorption or regeneration of the adsorbent is required. Highly favorable adsorption equilibria will require large volumes of regeneration gas and/or elevated temperatures for efficient desorption. Isotherm favorability may be characterized by a dimensionless derivative evaluated at the feed concentration of a proposed process

$$R_1 = \frac{c_{ref}}{q_{ref}} \left. \frac{dq}{dc} \right|_{c=c_{ref}} \quad (3)$$

The dimensionless isotherm derivative of the D-A equation is

$$R_1 = \frac{mRT}{\beta E} \left[-\frac{RT}{\beta E} \ln(p_{ref} / p_{sat}) \right]^{m-1} \quad (4)$$

For most applications, the best adsorbent would have a large capacity (large Λ) in order to minimize system size and would have a low favorability (large R_1) to maximize desorption efficiency. Figure 1 shows the partition coefficient calculated from the D-A fit at 25 °C for R-123 on various adsorbents. The bulk density and the void fraction of the adsorbents needed to evaluate Eq. (2) were approximated as $\epsilon = 0.4$ and $\rho_b = 500 \text{ kg/m}^3$ for all adsorbents. For a feed partial pressure of 10^4 Pa (10^5 PPM) R-123, MaxSorb has the greatest partition coefficient. However, at a feed partial pressure of 10^0 Pa (10^1 PPM) Norit has a greater partition coefficient than the MaxSorb. If the suitability of an adsorbent for use in removing a substance like R-123 is determined using the partition function of R-123 alone, then the MaxSorb is better at partial pressures above about 10^2 Pa ; however, at partial pressures between 10^2 Pa and about $10^{0.5} \text{ Pa}$ CAL or BPL may be the best choice. At still lower partial pressures ($10^{0.5}$ to 10^{-2} Pa) the Norit exhibits the best partition coefficient. Figure 2 shows the dimensionless isotherm derivative (Eq. 3, a measure of favorability) for R-123 on the same adsorbents. Favorability as used here implies a less efficient regeneration step and is not desirable in cyclic operations. The silica gel grade 59 is shown to have the greatest and therefore the most desirable dimensionless isotherm derivative. It is difficult to judge the importance of the isotherm favorability relative to the partition coefficient without a more detailed analysis. Clearly, an adsorbent must possess some adsorption capacity in order to provide for a separation. The magnitude required depends greatly upon many process variables including cycle time, adsorbent size, etc. Of the adsorbents with a reasonably large partition coefficient, R-123 is less favorably adsorbed on MaxSorb and on XUS 40285.00. In this case, the relative benefits of a high partition coefficient and a large dimensionless isotherm derivative (low favorability) have to be more carefully weighed. Other adsorbent properties (those not described by equilibrium data) may also be important in determining an adsorbent's suitability for use for a given application or process. Choosing the best adsorbent may require solving a full cyclic or single pass adsorption process optimization problem.

4. CONCLUSION

Adsorption isotherms were measured for R-123 on Rohm & Haas Ambersorb 563, Calgon Carbon BPL activated carbon and CAL liquid phase carbon, Kansai Coke & Chemical Co. Maxsorb G505Z30, Norit RD2030, Adcoa silica gel 408 and silica gel 59, and Dow polymeric resin XUS 40285.00 and XUS 43493.01. Data were measured for R-134a on Calgon Carbon BPL activated carbon, Sorb-Tech CL13 coconut shell carbon, and Adcoa silica gel grade 59. Toluene isotherms were measured on BPL, coconut shell carbon and silica gel 59. Data were collected over partial pressures ranging from the order of 10^{-2} to 10^4 Pa and over temperatures ranging from 0 °C to 200 °C. Experimental results were fit using the D-A equation.

Adsorbents were compared by plotting the partition coefficient and the dimensionless isotherm derivative versus the respective application feed concentration. The best adsorbent for a given separation (judged by the partition coefficient alone) was seen to depend on the application feed concentration.

When an adsorbent is the best for an application as judged by its partition coefficient but is not the best as judged by the dimensionless isotherm derivative (or other property), choosing the best adsorbent becomes a complex optimization problem. In order to solve such a problem the whole cyclic or single pass process must be considered.

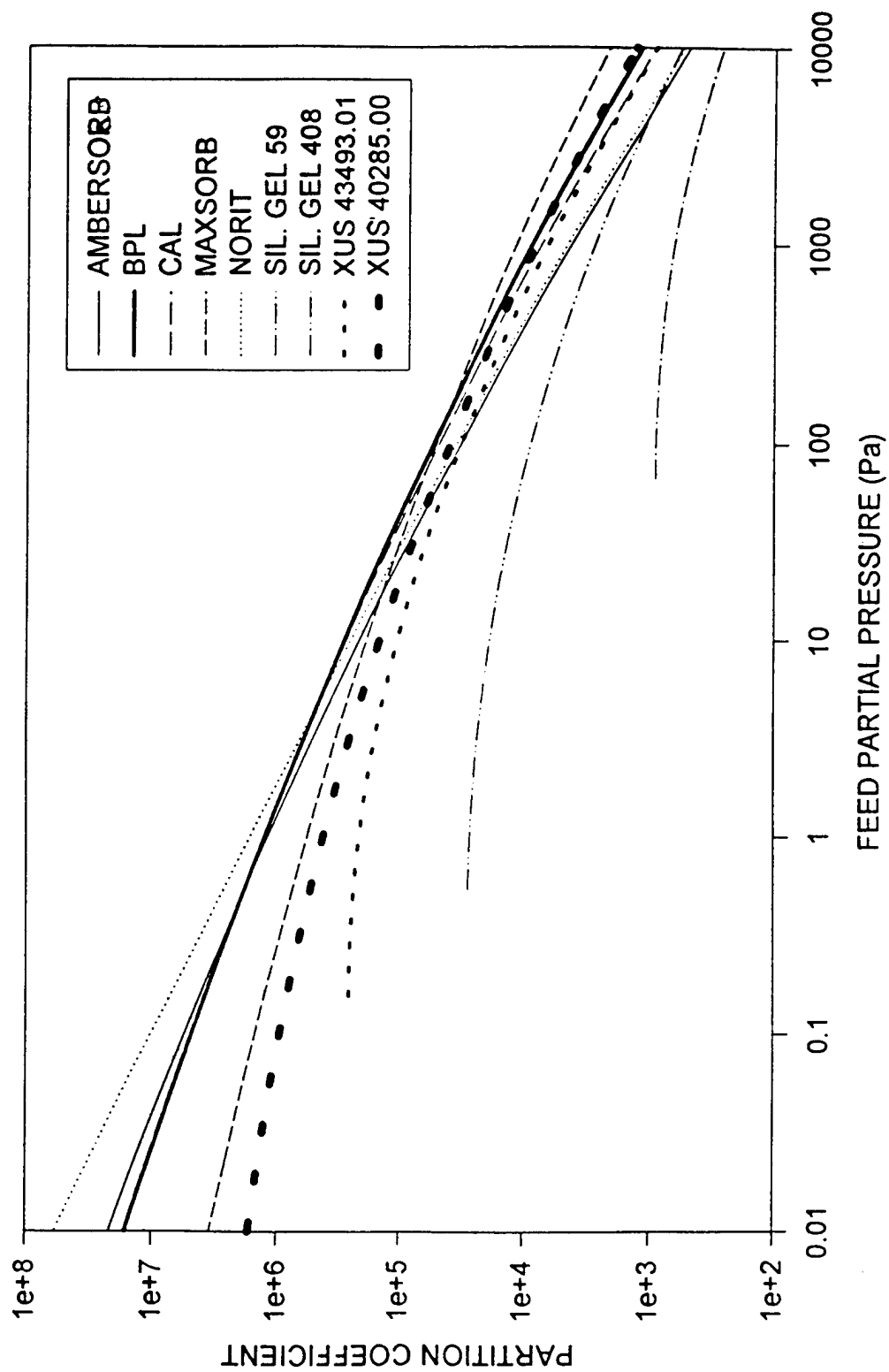


Figure 1. Comparison of R-123 Partition Between Adsorbed And Fluid Phases

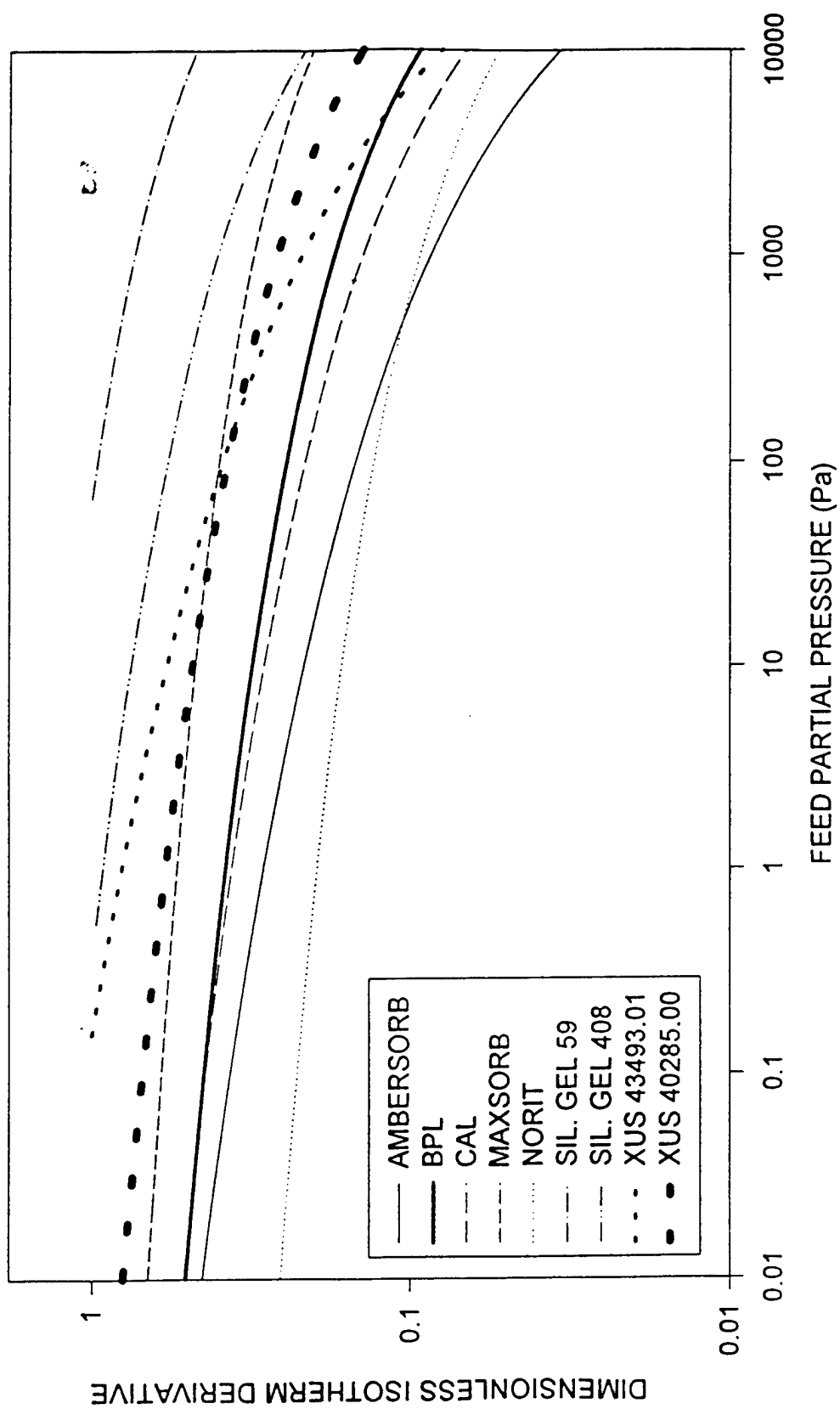


Figure 2. Comparison of R-123 Adsorption Favorability

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Adsorption Equilibria Data Tables

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TABLE A1. Experiment 02/21/95 R123/Amborsorb (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
						0.0269	0.03150	49.72
						0.1377	0.06743	49.77
			0.0242	0.1314	24.84	0.4561	0.1308	49.88
0.0498	0.2566	10.64	0.2106	0.2564	24.86	1.667	0.2542	49.54
0.4908	0.5065	10.18	1.684	0.5047	24.86	10.26	0.4918	49.58
16.85	0.9712	10.53	42.12	0.9332	24.95	113.7	0.8255	49.73
447.6	1.314	10.48	512.9	1.216	24.84	624.9	1.047	49.75
1664	1.536	10.55	1753	1.402	25.22	1895	1.189	49.61

TABLE A2. Experiment 02/02/95 R123/BPL (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
			0.1034	0.003986	100.9	0.9967	0.002572	152.0
			0.4388	0.01243	102.3	3.290	0.00792	152.1
			1.226	0.02864	103.3	8.203	0.01760	152.8
0.05261	0.06157	50.90	3.402	0.05626	103.6	18.05	0.03309	152.4
0.1376	0.1209	42.21	8.995	0.1069	102.0	38.90	0.05952	151.7
2.005	0.2431	51.08	28.22	0.2016	103.1	89.03	0.1053	152.7
10.37	0.4820	53.19	87.08	0.3606	102.3	202.1	0.1785	152.0
62.13	0.8981	52.14	263.2	0.5797	103.6	449.8	0.2843	153.7
			713.6	0.8921	101.8	1001	0.4376	150.7

TABLE A3. Experiment 02/09/95 R123/BPL (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
						0.0119	0.02605	49.84
			0.0187	0.07712	24.78	0.1613	0.07680	49.56
			0.0467	0.1700	24.86	0.7306	0.1684	49.64
0.1779	0.3510	10.54	0.6119	0.3500	25.06	3.622	0.3432	49.27
1.595	0.7153	10.72	4.802	0.7080	25.02	21.82	0.6694	49.71
18.18	1.415	10.44	43.62	1.358	24.93	123.7	1.176	49.63
205.7	2.481	10.49	311.2	2.241	24.74	507.7	1.795	49.21
1207	3.304	10.63	1359	2.957	24.89	1616	2.374	49.43
1201	3.304	10.53	1344	2.979	24.81	1590	2.420	49.64
1192	3.310	10.49	1336	2.983	25.25	1588	2.411	49.59

TABLE A4. Experiment 04/07/95 R123/Calgon Liquid Phase Carbon (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
			0.1190	0.1688	25.61	0.1452	0.07089	50.02
0.03270	0.3810	0.719	1.005	0.3786	25.11	0.8437	0.1670	49.70
1.329	0.8035	1.031	8.878	0.7848	25.83	5.157	0.3683	49.88
18.18	1.585	1.042	74.02	1.447	25.59	33.98	0.7225	49.38
						169.7	1.210	49.55

TABLE A5. Experiment 03/29/95 R123/Maxsorb (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
						0.0854	0.0108	49.47
			0.0528	0.0311	25.71	0.3567	0.0304	49.51
0.0190	0.07334	0.5044	0.2173	0.07289	25.12	1.224	0.07057	49.43
0.05626	0.1627	0.7108	0.8339	0.1609	25.43	4.147	0.1533	49.73
0.5571	0.3586	0.8831	3.719	0.3513	25.36	15.43	0.3244	49.45
2.864	0.7387	0.8822	15.97	0.7085	25.55	53.03	0.6233	49.95
15.29	1.451	0.8730	66.34	1.334	25.87	170.1	1.095	49.63
86.80	2.800	0.4579	269.2	2.381	25.58	512.7	1.821	49.59
			1031	3.729	27.74	1432	2.806	49.79

TABLE A6. Experiment 03/24/95 R123/Norit (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
						0.0195	0.01453	49.56
						0.05058	0.03362	49.60
			0.03459	0.07426	26.02	0.1829	0.07394	49.64
0.0201	0.1574	0.1924	0.1336	0.1571	25.04	0.5347	0.1563	49.59
0.1086	0.3375	0.1043	0.6227	0.3363	26.01	2.174	0.3330	49.52
0.6807	0.6955	0.1630	4.704	0.6868	25.62	19.19	0.6556	50.53
0.0000	0.0376	1.125	0.01318	0.03753	25.25	0.07258	0.03736	49.74
0.0000	0.0887	1.222	0.04124	0.0886	25.31	0.2073	0.0881	49.90
0.02351	0.1971	1.510	0.1730	0.1967	25.19	0.6679	0.1953	49.75
0.1589	0.4354	1.196	0.8394	0.4335	25.29	3.159	0.4270	49.80
0.0000	0.02943	0.4692	0.0000	0.02943	25.41	0.04557	0.02929	49.34
0.0000	0.08846	0.6094	0.0553	0.0883	25.17	0.1848	0.08789	49.12
0.0000	0.2129	0.6952	0.09443	0.2126	24.95	0.6632	0.2108	49.20
0.2126	0.4801	0.6835	1.0156	0.4776	25.18	4.097	0.4681	49.70
1.934	1.004	0.7851	12.41	0.9715	25.29	41.33	0.8820	49.66
131.6	1.627	0.6738	187.9	1.453	25.30	252.0	1.254	49.57

TABLE A7. Experiment 04/20/95 R123/Silica Gel Grade 59 (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
1.667	0.002734	1.235	2.591	0.000365	25.17			
5.381	0.008780	1.238	8.038	0.001969	25.58			
11.48	0.01568	2.019	15.69	0.004905	25.27	17.42	0.000448	49.34
24.56	0.02929	1.904	32.20	0.009702	25.21	34.97	0.002595	49.45
54.02	0.05497	1.345	68.13	0.01882	25.40	73.20	0.005803	49.47
122.0	0.1003	1.136	145.7	0.0396	25.14	154.5	0.01704	49.64
266.2	0.1703	1.125	306.9	0.0660	25.75	322.0	0.02715	49.62
567.0	0.2812	0.9394	632.1	0.1145	25.54	654.4	0.0573	49.22
1185	0.4773	0.9091	1289	0.2112	25.61	1332	0.1014	49.72
2572	0.7031	1.382	2647	0.5114	25.31	2696	0.3847	49.33

TABLE A8. Experiment 04/11/95 R123/Silica Gel Grade 408 (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
0.1046	0.006941	0.87	0.7585	0.006045	25.42	2.428	0.003756	49.37
0.3400	0.01883	0.98	2.120	0.01640	25.19	6.507	0.01038	49.35
0.9019	0.04274	1.31	5.391	0.03658	25.29	15.25	0.02308	49.52
2.679	0.09278	0.78	14.22	0.07696	25.74	35.79	0.04741	49.33
9.281	0.1958	0.96	39.97	0.1537	25.55	84.40	0.09281	49.49
34.03	0.3884	1.18	109.7	0.2847	25.81	193.7	0.1696	49.27
130.3	0.7087	1.19	296.0	0.4817	25.17	441.1	0.2828	49.77
473.1	1.139	0.54	758.7	0.7474	25.41	977.0	0.4483	49.43

TABLE A9. Experiment 02/16/95 R123/XUS 43493.01 Dow Resin (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
0.01899	0.00659	10.63	0.0922	0.006447	25.04	0.5256	0.005596	49.84
0.06016	0.0165	10.40	0.2010	0.01618	24.91	1.131	0.01435	49.49
0.1426	0.03674	10.32	0.4608	0.03611	24.58	2.435	0.03223	49.75
0.3554	0.07900	10.52	1.109	0.07752	24.96	5.683	0.06855	49.70
1.009	0.1571	10.63	2.763	0.1537	24.71	13.05	0.1335	49.62
2.835	0.3129	10.50	7.966	0.3028	24.98	32.80	0.2540	49.76
10.97	0.6200	10.74	27.20	0.5881	24.71	88.60	0.4675	49.68
51.30	1.171	10.38	104.6	1.066	24.92	244.8	0.7909	49.48

TABLE A10. Experiment 05/02/95 R123/XUS 40285.00 Dow Resin (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
0.0000	0.01724	1.09	0.05707	0.01690	25.42	0.4137	0.01481	49.91
0.0000	0.04393	1.22	0.1977	0.04277	25.64	1.092	0.03754	49.60
0.04705	0.09811	1.22	0.5612	0.09510	25.54	2.834	0.08179	50.41
0.2092	0.2069	1.49	1.819	0.1975	25.49	7.649	0.1634	49.72
1.023	0.4327	1.28	6.700	0.3994	25.63	22.45	0.3072	49.87
6.663	0.8993	1.04	28.62	0.7707	25.31	65.47	0.5549	50.12
46.44	1.649	1.29	112.3	1.264	25.62	181.3	0.8595	49.71
239.6	2.487	1.39	345.0	1.870	25.41	443.2	1.294	49.96
765.3	3.320	1.23	917.8	2.427	25.73	1040	1.711	50.00
2018	4.204	1.20	2193	3.176	25.42	2359	2.204	49.93

TABLE A11. Experiment 09/02/94 R134a/BPL (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
1.28	0.0057	51.77	4.10	0.0013	101.10	4.81	0.00024	150.00
5.78	0.014	51.50	12.67	0.0033	101.30	14.37	0.00066	150.19
14.42	0.027	51.99	27.73	0.0068	101.06	31.08	0.0016	150.71
36.11	0.053	51.48	61.66	0.013	100.99	68.34	0.0030	150.50
86.82	0.095	51.40	131.71	0.025	101.01	143.19	0.0076	150.19
198.24	0.16	51.42	274.79	0.044	100.80	296.08	0.011	150.32
449.69	0.26	51.56	569.38	0.079	100.91	604.59	0.025	150.48
980.45	0.41	51.53	1159.67	0.14	100.95	1219.41	0.045	150.09
1663.74	0.54	51.57	1894.35	0.19	100.90	1976.71	0.058	150.30

TABLE A12. Experiment 09/19/94 R134a/BPL (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
0.10	0.0074	9.42	0.31	0.0071	25.49	1.35	0.0055	49.75
0.61	0.022	10.72	1.51	0.020	25.50	4.77	0.015	49.72
2.20	0.050	10.33	5.07	0.045	24.72	13.48	0.032	49.63
7.36	0.101	10.48	15.16	0.089	24.75	33.87	0.060	49.59
24.42	0.197	10.23	43.87	0.17	25.02	81.38	0.11	49.98
77.04	0.357	10.35	120.57	0.29	24.65	190.64	0.18	49.55
235.87	0.61	10.44	319.32	0.48	25.10	435.99	0.30	49.57
647.00	0.95	10.28	786.31	0.74	24.73	967.70	0.46	49.85
1655.42	1.40	10.31	1873.28	1.07	24.53	2142.76	0.65	49.47

TABLE A13. Experiment 09/12/94 R134a/Coconut Shell Carbon (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
2.201	0.004237	51.53	4.429	0.000703	101.1	4.822	0.000081	150.2
7.295	0.01162	52.04	13.29	0.002119	101.0	14.38	0.000388	149.6
17.87	0.02625	52.00	31.18	0.005139	100.7	33.65	0.001231	150.2
39.95	0.05185	52.11	66.13	0.01034	101.3	71.23	0.002260	150.6
88.89	0.09927	52.24	137.7	0.02186	101.1	147.0	0.007154	150.3
193.9	0.1799	51.32	282.2	0.03983	101.1	301.3	0.009586	150.0
432.9	0.3098	51.72	576.5	0.08210	100.9	610.3	0.02849	151.0
939.4	0.5141	51.82	1172	0.1453	101.2	1233	0.04801	150.1

TABLE A14. Experiment 09/26/94 R134a/Coconut Shell Carbon (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
0.3091	0.008212	10.26	0.8018	0.007452	24.49	2.437	0.004929	49.58
0.9689	0.02289	10.21	2.404	0.02068	24.78	6.846	0.01382	49.57
2.675	0.05208	10.12	6.218	0.04661	24.73	16.27	0.03110	49.63
6.943	0.1056	10.50	15.19	0.09292	24.88	36.12	0.06064	49.87
19.72	0.2112	10.61	39.05	0.1814	24.59	80.61	0.1173	49.66
57.78	0.3983	10.26	101.6	0.3308	24.86	181.0	0.2083	49.30
180.8	0.7226	10.30	272.1	0.5818	24.88	411.8	0.3662	49.77
532.5	1.182	10.27	697.8	0.9269	25.26	920.9	0.5829	49.72
1488	1.771	10.15	1730	1.398	24.90	2048	0.9077	49.52

TABLE A15. Experiment 11/11/94 R134a/Silica Gel Grade 59 (glass jacket)

p(Pa)	q(mol/kg)	T(C)
16.19	0.002084	10.63
37.51	0.004606	10.27
79.28	0.009174	10.37
164.6	0.01732	10.38
338.2	0.03219	10.34
695.6	0.05694	11.01
1421	0.09805	10.14
2799	0.1844	10.37

TABLE A16. Experiment 09/18/95 Toluene/BPL (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
0.00	0.86	25.41	0.43	0.86	50.14
0.19	1.20	25.60	0.98	1.19	50.10
1.59	2.10	25.55	8.55	2.06	50.52
38.96	3.76	25.89	110.57	3.35	50.18
222.15	4.58	26.01	330.00	3.97	50.22
494.02	4.88	25.33	600.86	4.27	50.43
792.17	5.03	25.97	889.36	4.48	50.59
1095.13	5.15	25.70	1199.50	4.56	50.41
1380.37	5.18	25.84	1485.11	4.59	50.20

TABLE A17. Experiment 09/27/95 Toluene/BPL (glass jacket)

p(Pa)	q(mol/kg)	T(C)
0.51	1.66	25.45
21.78	3.43	25.89
165.50	4.36	25.50
422.68	4.68	25.86

TABLE A18. Experiment 10/11/95 Toluene/BPL (copper jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
0.00	0.80	50.64	4.16	0.78	100.02	32.96	0.63	149.79
0.41	1.08	50.23	10.74	1.03	99.80	59.36	0.79	149.55
3.59	1.79	50.19	49.54	1.56	99.77	148.40	1.07	149.83
65.00	3.04	50.14	228.63	2.23	99.61	387.28	1.45	149.54
239.60	3.70	50.19	459.31	2.62	99.86	645.76	1.70	149.37
491.68	4.01	50.32	729.59	2.83	99.85	911.79	1.93	149.79
762.87	4.20	50.20	992.36	3.07	100.15	1196.78	2.06	149.55
1058.36	4.31	50.28	1294.55	3.14	99.92	1516.10	2.05	149.53

TABLE A19. Experiment 08/03/95 Toluene/Coconut Shell Carbon (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
1.18	1.80	25.90	7.85	1.79	49.91
369.60	2.83	25.33	440.77	2.66	49.92
1360.56	3.46	25.54	1487.59	3.15	49.84

TABLE A20. Experiment 08/11/95 Toluene/Coconut Shell Carbon (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
10.69	2.73	25.84	37.97	2.59	49.97
473.35	3.35	25.37	520.69	3.11	49.65
473.35	3.35	25.37	1083.89	3.25	50.16

TABLE A21. Experiment 8/16/95 Toluene/Coconut Shell Carbon (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
193.07	3.34	25.83	265.83	3.11	49.70
736.90	3.53	26.08	806.56	3.31	50.03
1244.49	3.77	25.76	1359.53	3.40	50.09
1866.09	3.74	25.92	1953.14	3.46	49.91
2344.74	4.13	25.88	2575.30	3.40	50.11
3125.31	3.85	25.85	3259.35	3.43	49.78
3578.80	4.31	25.68	4082.31	2.71	49.70

TABLE A22. Experiment 12/22/95 Toluene/Coconut Shell Carbon (copper jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
0.084	0.028	149.48	0.227	0.0086	198.96

TABLE A23. Experiment 01/03/96 Toluene/Coconut Shell Carbon (copper jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)
1.15	0.55	99.40	5.24	0.53	125.63	14.53	0.48	149.65
36.92	1.57	100.41	79.00	1.35	126.05	124.31	1.12	149.26
37.86	1.63	99.23	82.24	1.40	124.91	130.92	1.15	148.61
37.72	1.63	98.91	84.63	1.39	125.88	133.14	1.14	149.60
36.12	1.63	98.93	81.31	1.40	125.50	131.13	1.14	149.42

TABLE A24. Experiment 06/08/95 Toluene/Silica Gel Grade 59 (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/g)	T(C)
2.50	0.06	1.25	7.93	0.04	25.29	15.32	0.021	49.86
8.75	0.14	0.90	28.65	0.09	25.55	45.30	0.046	49.43
27.31	0.33	0.76	72.86	0.21	25.82	117.96	0.085	49.88
88.02	0.70	1.02	206.84	0.38	25.52	282.74	0.176	49.60
296.56	1.37	0.94	539.85	0.72	25.59	672.26	0.360	49.68
537.44	3.11	0.91	1223.46	1.26	25.63	1486.91	0.555	49.52
691.37	7.44	1.33	2319.92	3.06	25.38	3140.28	0.850	49.50

TABLE A25a. Experiment 06/20/95 Toluene/Silica Gel Grade 59 (glass jacket)

p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/kg)	T(C)	p(Pa)	q(mol/g)	T(C)
1.67	0.048	1.43	2.75	0.045	5.86	4.45	0.040	10.97
7.50	0.14	0.84	10.18	0.13	6.10	14.63	0.12	11.03
25.30	0.30	1.22	32.48	0.28	5.56	42.43	0.25	11.31
84.21	0.69	1.05	102.85	0.64	6.06	126.22	0.58	11.05
311.86	1.32	0.74	363.15	1.18	6.05	425.70	1.01	10.90
560.96	3.16	1.05	702.93	2.77	5.57	866.06	2.32	10.87
699.41	7.29	1.08	939.55	6.62	6.04	1246.99	5.78	10.73
955.91	12.40	1.34	1241.47	11.61	5.60	1656.33	10.47	11.19
			1483.29	16.17	5.68	1889.84	15.04	11.19

TABLE A25b. Experiment 06/20/95 Toluene/Silica Gel Grade 59 (glass jacket)

p(Pa)	q(mol/g)	T(C)	p(Pa)	q(mol/g)	T(C)
5.31	0.038	15.93	6.86	0.034	20.90
19.05	0.11	16.30	23.88	0.10	20.61
52.19	0.22	16.32	61.73	0.20	20.86
159.69	0.48	16.25	183.57	0.42	20.55
468.65	0.89	16.25	505.62	0.79	20.61
1011.52	1.92	16.02	1136.34	1.58	21.25
1638.51	4.70	15.91	2035.49	3.60	20.81
1783.02	10.12	15.83	2198.13	8.97	20.91
2448.11	13.50	15.94	3279.64	11.21	20.43

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